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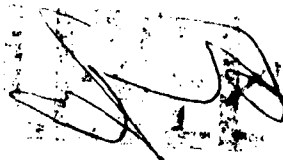


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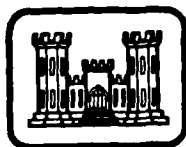
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## HIGH-LUMINANCE ROAD SURFACES

T. Thurmann-Moe and S. Dørum



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UNITED STATES ARMY  
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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY  
HANOVER, NEW HAMPSHIRE, U.S.A.



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The road surface is an important factor for the visibility conditions of night driving. The most important characteristics are the structure and the luminosity of the surface. These characteristics have been proven to have major significance for visual guidance, recognition of obstacles, and glare. In order to obtain maximum effect, the luminosity of the road surface must be produced by the particles protruding up from the surface, i.e. the coarsest portion of the aggregates. The usefulness is determined by the durability, the		

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resistance to weathering, and the degree of luminosity. Quartzites have the best wear properties and anorthosites are lighter in color. The field tests have confirmed the positive effect of a light-colored road surface or a light-colored shoulder on the recognition of obstacles on the road. The tests have also shown satisfactory wear characteristics of those light-colored aggregates that had been selected on the basis of laboratory testing.

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## HIGH-LUMINANCE ROAD SURFACES,

by

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### PREFACE

Since the early 1960's, the Road Laboratory has been investigating the problem concerning the contribution of the road surface to visibility conditions for driving in darkness, by means of measurements and observations in test areas and on regular road sections as well as in searching systematically for suitable light-colored rock materials. The purpose of these studies has been to develop a suitable method of constructing light road surfaces and to measure the effect of these in respect to improved visibility when driving in darkness.

The starting point for the investigations by the Road Laboratory has been to study and to improve the conditions on roads without fixed illumination, and many of the results and conclusions are primarily applicable to such conditions. However, it has also been found that "luminous" road surfaces are also advantageous in those cases where the roads are permanently illuminated.

### INTRODUCTION

When compared to daytime traffic, the amount of transport activity which is performed at night is very small. In spite of this fact, a great proportion of serious accidents occurs during the dark hours. Studies from the period 1960 - 1970 show that in the United States, England, and Belgium, approximately 50% of all fatal accidents occurred in darkness; in Denmark and Sweden, the figure was approximately 40% (1). The corresponding figure for Norway is somewhat lower insofar as approximately 35% of fatal traffic accidents and 25% of the total number of traffic accidents with personal injuries occurred in traffic during the dark hours, on illuminated and non-illuminated roads combined. Thus, the problem is less extensive in Norway than in our neighboring countries. But if the accident risk in daylight and on dry roads is set at 1, the risk factor

respectively, for daylight and wet road surfaces, darkness and dry road surfaces, and darkness and wet road surfaces will be found to be approximately 2, 1.5 - 3, and approximately 10. Consequently, the problem is serious in our country as well.

The traffic accidents are characterized either by the vehicle going off the road, or by collisions with other vehicles or persons on the road. In this respect, the accidents can be traced to lack of visual guidance, i.e. that the driver does not have a satisfactory visual image of how the road turns, or insufficient visual images of obstacles on the road.

#### TECHNOLOGICAL CONSIDERATIONS CONCERNING LIGHT

For driving in darkness, two characteristics of the road surface proper and its surroundings are of particular importance, namely

- visual guidance
- discovery of obstacles.

Other factors that must also be taken into consideration are not related solely to the road surface, such as glare, etc.

##### Visual Guidance

Visual guidance is created by the visual signs relating to the driver how the road proceeds through the terrain and assisting him in staying on the road and in the proper driving lane.

Visual guidance can be achieved in several ways, and for some of these, the road surface is of minor importance. Most important are fixed road illumination, reflectors on the road, edging lines, roadside posts, light-colored barriers, etc. Visual guidance can also be achieved if the surface of the road or its shoulder reflects more light than does the surroundings.

American studies show that if the driver can see the closest 30 m of the road, he can normally select a suitable and reasonably constant speed (2). Thus, good visual guidance creates a feeling of security in the driver and reduces the strain of night driving. However, this feeling of security may be false, if he does not, at the same time, recognize potential obstacles on the road.

##### Visibility of Obstacles

The driver must not only see the stretch of road before him but also the obstacles on the road early enough to act to avoid them. Conversely, he must also be assured that a road where no obstacles can be seen is indeed free of such obstacles. This presupposes that the contrast between the road surface and the potential obstacles is so great that the driver recognizes the obstacle at a distance which is related to his speed. This depends on the fact that the amount of light reflected by the road surface towards the driver is different from that reflected by the obstacle; i.e., the possibility of recognizing e.g. pedestrians is dependent on both the road surface and the clothes of the pedestrian as well as on the environment. Studies performed by E. Fredriksen (3) show that the critical visual distance (the maximum visual distance) to an object on a road without fixed illumination will increase with the retro-reflection capability of the road surface (See Figure 1), disregarding the color of the object. The same investigation shows that differences in critical

visual distance for light-colored and dark objects decreases as the retro-reflection of the road surface improves, and this is of great importance for correct estimation of the distance to potential objects on the road. Others have made similar findings, as can be seen, for instance in (4).

These considerations demonstrate that so-called luminous road surfaces with good light reflection characteristics are advantageous both for visual guidance and for the ability of the driver to recognize and judge the distance to obstacles on the road.

However, it is not enough that the light reflection is satisfactory on some parts of the road surface. It must also be uniform, so that the entire road surface is visible as evenly as possible.

#### Visibility of Road Markings

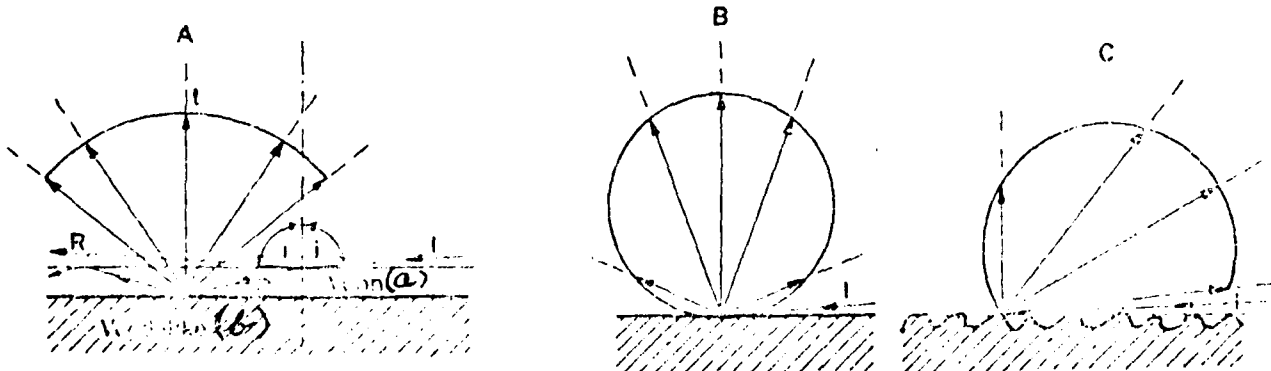
The contrast between road surface and road markings may suffer when the road surface is light-colored. It has been demonstrated that the difference in retro-reflection from the edge line and from the road surface must be at least  $0.02 - 0.03 \text{ cd/m}^2 \text{ lux}$  on a road without fixed illumination in order for the markings to be visible from a sufficiently great distance (3). This poses certain requirements not only on the color of the edge lines but also on the structure of the road surface. Further, this requires certain limitations on the luminosity of the road surface so that it may have a lower luminance than the road markings during its entire useful life.

FIGURE 1: Different principles of light reflection (I = Incident light)

A: Mirror reflection

B. Diffuse reflection

C: Retro-reflection



(a) Water

(b) Road surface

#### Glare

A differentiation is made between glare that directly decreases the vision and glare which is merely unpleasant. Both types have a negative effect on traffic safety.



Glare from the road surface occurs when lights from on-coming traffic are reflected from road surfaces in a mirror-like way. One may also be blinded by the lights from one's own car. This is quite common when curve/fog lights are used under normal driving conditions, when the road immediately in front of the vehicle is very highly illuminated and thus decreases the vision in more normally illuminated road portions further ahead. This unfavorable effect causes a decrease of the critical field of vision, and it is greatest on road surfaces which are advantageous from the point of view of technology of light, i.e. road surfaces with a high degree of retro-reflection.

Glare may also occur in daylight when road surfaces with maximum luminance effect for night driving become too luminous in daylight.

#### VARIOUS MEANS OF IMPROVING VISIBILITY CONDITIONS

The previous text emphasizes the importance of good visual guidance and effective contrast between road surface, road markings, and surroundings for improving the lighting conditions for night driving on roads with and without fixed illumination. Further, it must be possible to discover and to judge the distance to obstacles on the road, and the drivers should be exposed to a minimum of glare.

Currently, many methods are used simultaneously in order to fulfill these objectives, but no total system for coordinated use of the various means has been developed. A more detailed description of various optical methods is given in (5). Here, some of these will be discussed in order to reveal what factors are significant for efficiency and what limitations these are subject to.

##### The Road Surface of the Driving Lanes

Visibility problems will particularly occur in rainy weather, when the road surface is covered by a water film of variable thickness. If the road surface is not rough but has a finely grained surface, it will be covered by a more or less unbroken water film under such conditions. In this case, the water film determines the optical characteristics of the driving lane, no matter what the color of the road surface proper.

A road covering with coarsely grained surface and with good run-off will continually drain-off the water and any water film will be broken-up by the projecting points of the surface, i.e. the projecting particles will largely determine the luminosity characteristics of the road surface under wet conditions.

The requirement for the road covering is that it must reflect back to the driver, as much as possible, the light from the car and, if applicable, from the road illumination. Thus, the retro-reflection of the road surface must be as great as possible and the surface must not produce a mirror-effect. It is obvious that this requirement can only be fulfilled if the surface has an appropriately coarse structure. Without such a coarse structure, the color of the road surface is of little or no importance in rainy weather, and the color of the coarse particles in the road surface are of greatest importance for the luminosity of the road covering. This condition is illustrated in Figure 1.

In a common, standard mix surface, a high proportion of fine gravel above approx. 10 mm and a moderate proportion of sand will contribute to a good coarseness of the structure, and since the coarsest particles contribute to the luminosity characteristics, the gravel should be light in color. However, the durability requirement demands a dense surface with the least amount of cavities possible, and this limits the quantity of coarse components to approx. 45%.

With respect to wear and tear, a high proportion of coarse material is advantageous provided it has good mechanical properties. Furthermore, a high gravel content also improves the friction characteristics of the road surface.

That type of road covering which immediately appears as particularly advantageous is a single layer surface treatment. This consists of fine gravel levelled uniformly to a thickness of one stone which is bonded to an asphalt layer by means of a thin layer of binder. Surface treatment of this type results in a very coarse surface with good drainage, and if the rock material is of a light color, it would also give a maximum effect from the point of view of the technology of light.

However, surface treatment has limited useful life, and it is currently recommended only for roads with a daily traffic load of less than 3,000. The surface type is nevertheless of interest as a light-colored driving lane surface.

Rolling of fine gravel into a hot surface immediately after spreading is now required for all Topeka and asphalt concrete new road surface coverings in order to create a friction surface. This treatment results in a very coarse surface with good drainage. Usually, the fine gravel is asphaltized, and some time will pass before the binder film on the surface is worn off. Thus, even though light-colored fine gravel has been used, the road covering has a rough but black surface to start with.

The effect, however, is not lasting since the fine gravel is relatively rapidly worn off in the wheel tracks. Thus, treatment with light-colored fine gravel is no independent alternative but is only recommended in those cases when the road covering itself also contains light-colored rock material.

#### The Surface of the Shoulders

The same standards for road surface reflection characteristics also apply to the shoulder surfaces. The most important differences will be found in the different effects on visibility conditions and in the low intensity of traffic on the shoulder. Furthermore, it is more difficult to keep the shoulder surface free of sand, dirt, snow, etc. than to clean the surface of the driving lanes.

It can be assumed that a road with a common, dark surface on the driving lane and a light-colored, retro-reflecting surface on the entire width of the shoulder would give good visual guidance but unsatisfactory effect in respect to obstacles in the driving lanes.

Measurements of visibility distances which have been performed by the Road Laboratory (more about these later) would indicate, however, that obstacles with the height of an adult person will appear as silhouettes against the lighter shoulder, and that this solution would thus also contribute to improved recognition. Such a specialized treatment of the shoulder surface is therefore of interest as "luminous surface", although with certain reservations.

Surface treatment with light-colored rock material is also an obvious solution for obtaining a luminous shoulder surface.

This would have the advantage that those light-colored rock materials which are less durable than the best dark ones would be used for that part of the road surface which is subjected to less wear. On the other hand, a surface treatment requires an even traffic-generated compression in order to have a long useful life. In order to compensate for this, it is common to use a significantly greater quantity of binder than is the case with surfaces with average traffic density. The disadvantage is that the binder is easily pushed up into the surface and becomes black and shiny, if the shoulders are used for driving. Furthermore, the shoulder should have a covering which is not unpleasant for pedestrians and cyclists, and the surface structure must therefore not be too coarse.

In order to increase the retro-reflection by surface treatment, the covering of the shoulder can be lightly sprayed with small glass beaded paint. These must be applied at an angle so that only that side of the gravel grains facing the driving direction of the closest lane will be sprayed.

#### INVESTIGATIONS OF MATERIAL TECHNOLOGY AND MEASUREMENTS OF LUMINOUS EFFECTS

In the preceding, light-colored road surfaces have been discussed from theoretical points of view, and arbitrary evaluations have been made of the alternatives of interest in respect to effect and practicality. Two major questions must be answered before indications can be given for application of light-colored road surfaces:

- demonstration of the availability of light-colored rock material with satisfactory usage characteristics, and
- development of an optimal composition of the most interesting surface alternatives, and measurement of the attainable luminous effect.

These problems can be solved only by systematic searching out and quality testing of light-colored rock materials, and by application and follow-up studies of test areas on normally frequented roads.

#### LIGHT-COLORED ROCK MATERIALS, LABORATORY INVESTIGATIONS

##### Search

In the late 1950's, a systematic search was commenced for deposits of light-colored rock with appropriate usage characteristics and locations. Close to a hundred deposits have been evaluated; most of these have been investigated at the Road Laboratory, and 15 - 20 have been subjected to additional testing in the field on ordinary roads.

When the investigations were initiated, the main requirement was that the rock material would be resistant to wear by snow chains. This condition was changed with the decreased use of snow chains and increasing use of studded tires. The studded tires wear down the road surface in a different manner than do the chains. For instance, the brittleness is no longer of the same importance for good durability. This increased the possibilities of using some light-colored rock materials that could not previously have been recommended,

including anorthosites and quartzites. The former deposits were not advantageously located in respect to optimum nationwide distribution. The anorthosites have been found particularly in western Norway, where a couple of major deposits have been quarried for some time. Quartzites in worthwhile quantities have been found in the southernmost parts of the country, but regular quarrying has not been begun.

In the hope of decreasing the transporting distances, a new search for usable deposits was initiated in 1977. The search activities have been concentrated specifically to the inner east parts of the country. Several interesting deposits have been found, but the final mapping has not yet been completed.

Type of rock	Color (L: light) (D: dark)	Brittleness in fall test (% going through a sieve of 8 mm)	Abrasion (cm <sup>3</sup> )
Jasper	D	43	0.24
Quartzite	L	--	0.25
Quartzite	L	--	0.27
Granitic porphyry	D	35	0.28
Quartzite	L	46	0.31
Hornfels	D	25	0.34
Anorthosite	L	45	0.40
Hyperite	D	--	0.46
Quartz diorite	L - D	--	0.47
Sparagmite	D	34	0.49
Anorthosite	L	38	0.52
Gabbro	D	39	0.53
Basalt	D	27	0.55
Diorite	L - D	49	0.57
Granite	L - D	25	0.58
Anorthosite	L	35	0.59
Sandstone	D	45	0.65
Gneiss	D	31	0.80

FIGURE 2: Brittleness and abrasive resistance of some light and dark aggregates.

#### Mechanical Properties

The usefulness of the rock material, the aggregate, in surfaces subjected to wear is determined by a combined evaluation of durability as defined by abrasion and brittleness. The abrasion must be as low as possible, and the brittleness must fall within the requirements of the guidelines.

Figure 2 shows that most of the light-colored aggregates that have been studied are equal to or exceed the common, darker aggregates with respect to durability.

### Light Reflection Capability of the Aggregates

In the evaluation of light-colored aggregates for road surfacing purposes, there is a need for a common standard to characterize the luminosity under dry conditions and possibly also in particularly high humidity. Until recently, this was done subjectively. Some objective methods have been proposed (6), (7), but have not become widely used.

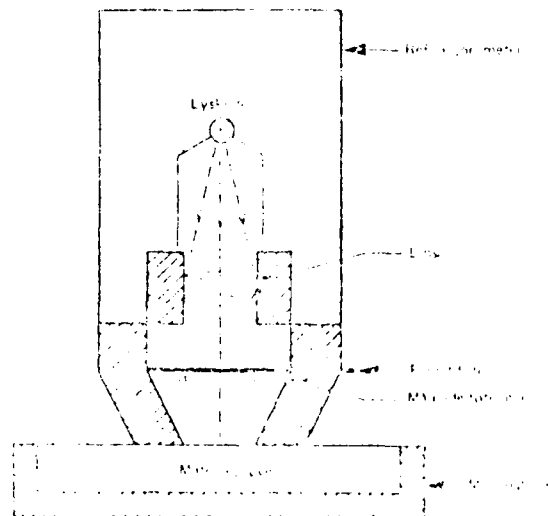
For this reason, the Road Laboratory initiated experiments in order to develop a practical method for objective measurement of luminosity.

Figure 3 shows the principle of the measuring instrument being used. The measurements are performed on the size fraction 50 - 100 (0.297 - 0.149 mm), and the sample must be moist.

FIGURE 3: Principle of the reflection meter.

(Inside the figure, at top: Light source; at bottom: Material sample.)

(At right, top to bottom: Reflection meter; Lenses; Colored filter; Measuring photocell; Brass container.)



Characteristic values for some common road surfacing materials are represented in Figure 4.

Based on these values, the material has been divided into 4 classifications, as indicated in Figure 5. For the time being, these classifications will be used for identifying aggregates with respect to light reflection capability.

The classification determines the quantities of light-colored material that must be added to common material to obtain a so-called luminous cover.

The following guidelines are recommended:

A Luminous road covering should contain no less than 20% additional material of luminosity class 1 or no less than 30% of luminosity class 2.

The light-colored additional material should be of granular size 11.2 - 16 mm.

FIGURE 4: Characteristic measured values (%) with a reflectometer on wet aggregate specimens, size fraction 0.149 - 0.297 mm.

Aggregate	Luminosity (% of MgO white)
Anorthosite	45
Quartzite	35
Sparagmite (gravel)	20 - 25
Granitic gneiss (gravel)	10 - 15
Basalt	
Amphibolite	4 - 6
Hyperite	

FIGURE 5: Classification of aggregates according to light reflection in wet condition.

Luminosity class	Characteristic	% Luminosity
1	Very light	> 35
2	Light	20 - 35
3	Somewhat light	10 - 20
4	Dark	< 10

#### LUMINOUS ROAD COVERINGS, FIELD TESTS

##### Test Area at Asker

The first field test with light-colored aggregate addition to road covering materials included two separate deposits of white anorthosite and a light grey menaccanite. These were used both as single layer surface treatment for traffic lane and shoulder and as additive in standard asphalt and gravel concrete mix Agb 16. The anorthosite was used both as 35% additive and alone, and both with and without substances for adhesiveness improvement.

The test areas were located on a road with an average daily traffic frequency of approximately 7,000. The purpose was primarily to measure the durability, but some evaluations of light reflection characteristics were also made.

The road coverings were applied in 1961 and had the following useful life in the actual traffic:

- Surface treatment of driving lane with anorthosite and menaccanite worn out in wheel tracks after 2 - 3 months, after 1 - 2 years only narrow strips of the surface treatment remained.
- Asphalt gravel concrete mix with menaccanite and 100% anorthosite was worn out after 4 years.
- Asphalt gravel concrete mix with 35% anorthosite without hot tar was worn out after 5 years.
- Asphalt gravel concrete mix with 35% anorthosite with hot tar was worn out after 6 years.
- Reference surface was worn out after 6 years.

Generally, the mechanical properties of the aggregates correspond to flakiness and brittleness classification 2 for all materials, with a tendency towards somewhat high flakiness.

Evaluations of the reflection characteristics showed, e.g. that surface treatment of the traffic lane with white aggregate definitely resulted in the best luminous effect and that an increase from 35% to 100% anorthosite in asphalt gravel concrete mix gave little improvement. This might indicate that it is mainly material coarser than 4 - 5 mm that contributes to the luminosity characteristics of the surface covering. A common asphalt gravel concrete mix with good basalt aggregate was used as a reference.

#### Test Area at Vinterbru

The next test area (9) included a new anorthosite deposit, the synthetic material Synopal, and a granite gravel in an asphalt gravel concrete mix, and a good gabbro for surface treatment for purposes of reference. With respect to flakiness and brittleness, the mechanical properties of the aggregate corresponded to class 2 for all except Synopal, which was very brittle. The composition and location of the test surfaces can be seen in Figure 6. The traffic on the test stretch was on the average approximately 3,000 vehicles daily in 1965; the distribution of studded tires and snow chains is not known. The proportion of studded tires increased very strongly during the period, while the proportion of chains was generally constant or decreased somewhat.

In order for the surfaces to reach their natural color and surface structure, they were left for two years before the measurements were made for wear. After three years, the wear was relatively insignificant in all of the areas and was found to be in the range between 3 and 8 mm. None of the areas was extraordinary in any respect. Little tracking was found on that part of the test area covered with asphalt concrete, but the track effect was obvious on the surface-treated stretches. The surface treatment with 50% light-colored and 50% dark aggregate showed that the durability was approximately the same but that the white material showed somewhat more cracking.

In order to be able to evaluate the areas from the point of view of light technology, visual distance measurements were performed by means of jury observations. Each individual area was designed with a length such that it would be possible to visually evaluate the luminosity effect while driving over the areas.





FIGURE 6: Text in box at right in figure.

AREA	T R E A T M E N T   O F	
	TRAFFIC LANE	SHOULDER
1.	60 kg/m <sup>2</sup> Agb 10 normal 6% bitumen, grade 180-200.	No treatment.
2.	As Area No. 1.	Surface treatment with 10-13 mm anorthosite.
3.	As Area No. 1.	Surface treatment with 10-13 mm anorthosite + white stripe painting.
4.	As Area No. 1.	White stripe painting.
5.	60 kg/m <sup>2</sup> Agb 13 90% anorthosite + 10% sand + 6.5% bitumen, grade 180-200.	No treatment.
6.	60 kg/m <sup>2</sup> Agb 13 31% Synopal + 69% sand/gabbro/ filler + 6.5% bitumen, grade 180-200.	No treatment.
7.	Surface treatment: 100% anorthosite 10-13 + 1.4-1.5 kg/m <sup>2</sup> RC4 + amine.	No shoulder.
8.	Surface treatment + 50% anortho- site 10-13 + 50% gabbro 3/8"-1/2" + 1.4-1.5 kg/m <sup>2</sup> RC4 + amine.	No shoulder.
9.	Surface treatment: 100% gabbro 3/8"-1/2" + 1.4-1.5 kg/m <sup>2</sup> RC4 + amine.	No shoulder.

When the light was measured, it was necessary to consider not only the luminous effect of the road covering proper but that of the surroundings as well. Thus, it was not possible to measure the luminance of the surface by means of any known measurement equipment. The light measurement per se had to comprise the total light effect. This was measured with the aid of the visibility range of individual observers in darkness, in rain, and under various light conditions (10), (11), (12).

Five independent observers participated, and persons dressed in both light and dark clothing served as obstacles. A total of 140 individual observations were made (16 with person in light clothing) with light from behind and from

ahead, and with good reproducibility. The observations were made in accordance with a carefully predetermined procedure, and the arrangement of light, light from ahead, and obstacles were made according to fixed rules.

For light from ahead, a car was parked with its headlights set at low beam 30 m from an observer car and with its lights directed towards the latter. The results of the observations of a person in dark clothing can be seen in Figure 7.

FIGURE 7: Visibility range with different road surfaces in rainy weather.

No.	AREA Description	VISIBILITY RANGE IN METERS	
		Light from ahead	Light from behind
2.	Dark Agb 13 Light shoulder	48	54
3.	Dark Agb 13 Light shoulder + stripe	45	59
7.	Light surface treatment No shoulder	40	51
5.	Light Agb 13 Gravel shoulder	35	45
8.	Somewhat light surface treatm. No shoulder	35	45
9.	Dark surface treatment No shoulder	35	45
6.	Somewhat light Agb 13 Gravel shoulder	32	46
Ref.	Dark Agb 13 Gravel shoulder	30	38

An interview study was also carried out in order to obtain the opinions of motorists on the luminosity characteristics of these road surfaces. In this study, the area with light surface treatment with anorthosite scored highest. However, the results of the interviews have only limited importance, since some of the areas were illuminated by fixed street lamps.

Later, surface samples from the same areas have been measured for their luminosity under laboratory conditions and with specific measuring equipment set up for this purpose. The measuring results from these and other surface tests will be reported in a later article.

The evaluation of the results shows that the most effective recognition seems to be achieved with white surface treatment of the shoulder with the usual surface for the traffic lane. In rainy weather on a dark road, these offer a visibility distance of 45-48 m with oncoming traffic. This is followed by white surface treatment, with a visibility distance of some 40 m. Speckled and dark surface treatment, Agb 13 with white coarse fraction with anorthosite or Synopal all result in a lesser light effect with visibility distances of approx. 35 m. The reference area is a common dark asphalt gravel concrete and a gravel-covered shoulder; this area has the shortest visibility range, namely approx. 30 m.

Given the distribution of studded tires and chains at this time in the traffic of the densely populated area in the Oslo region, white anorthosite of a uniform and unweathered type is usable as an additive to asphalt concrete and wear surfacing for asphalt gravel concrete on heavy traffic stretches. The upper traffic load limit for surface treatments with anorthosite is about 3,000 vehicles per day or possibly slightly more.

#### Test Area at Holmestrand

Here, the main purpose was to investigate the durability of two quartzites which had given very good abrasion results in laboratory testing. Furthermore, a comparison was desirable between these quartzites and previously approved materials, namely a light-colored anorthosite and a darker, durable hornfels (13).

These four aggregates were used as filler additives in Topeka, and the test range consisted of 4 areas of approx. 200 m, one traffic lane wide, with a different fine filler in each. Figure 8 shows the location of the areas. The average daily traffic load over a year was approximately 7,500 vehicles for the year when the surfaces were laid (1974).

Equal volume proportions of each one of the aggregates in the covering mass was assumed. However, it was found that the different fine filler variants were delivered with partially very different grading. For this reason, the volume proportion of fine filler in the final road cover varied. This must be considered when the results of the wear are evaluated. Figure 9 shows the actual fine filler content and the wear.

Compared with the laboratory findings, the results are not unequivocal. Quartzite 1 was more worn on the road than indicated by the laboratory result. On the other hand, quartzite 2 gave realistically little wear in spite of a low volume proportion of fine filler. However, the general conclusion must be that all of the three light-colored fine filler variants can be considered satisfactory, at least after 3 years of studded tire traffic. The luminosity characteristics of the road surface were not evaluated in this test.

#### COST CONSIDERATIONS

With the locations of the currently known deposits, mainly on the coast, it is calculated that the increase in construction cost will be approximately 10%, i.e. NCr 15,000 - 20,000 per kilometer, if light-colored aggregates are used for road surfaces.

Formerly, the mechanical properties were generally less satisfactory than those of the common, dark materials.

**FIGURE 8:** Field trial sections with Topeka mixtures containing different aggregates.

[From the top: Area 4 - hornfels; Area 3 - quartzite 2; Area 2 - quartzite 1; Area 1 - anorthosite. Rectangles at right in figure contain identifications of km posts along the road, E 18.]

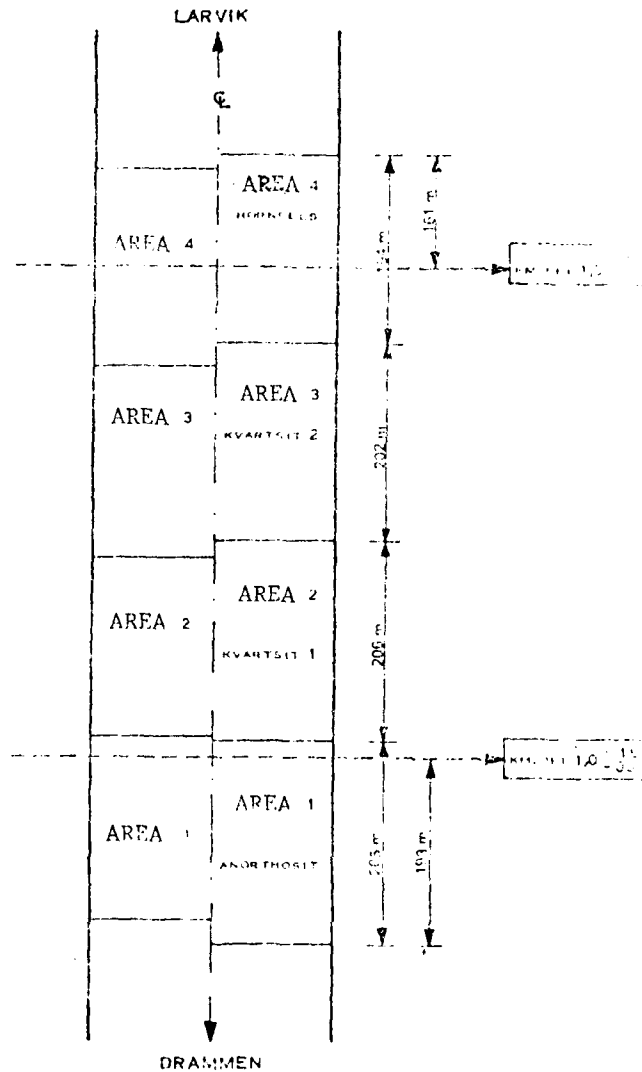


FIGURE 9: Road surface wear with different aggregates

Area	Fine filler	Fine filler content $> 3/8"$		Wear *)	
		Mass %	Volume %	mm	%
1.	Anorthosite	38	34	3.20	118
2.	Quartzite (1)	37	33	3.60	133
3.	Quartzite (2)	30	26	2.85	105
4.	Hornfels	41	35	2.70	100

\*) Average wear over the width of the traffic lane, 2 years. Due to sanding [?], the wear during the first winter season has been eliminated.

However, the durability of those light-colored deposits which are currently used is equal to that of the traditional dark materials, and thus, the useful life is of approximately the same length.

There are advantages of light-colored road surfaces when there is fixed road illumination. Calculations (14) show that both construction costs and annual operations costs can be reduced by some 10-30%, depending on the design, when a light road surface is applied. These savings may amount to approx. NCr 50,000 per kilometer for construction costs and some NCr 5,000 per kilometer for annual operations costs.

#### EVALUATION SUMMARY

The road surface is an important factor for the visibility conditions of night driving. The most important characteristics are the structure and the luminosity of the surface. These characteristics have been proven to have major significance for visual guidance, recognition of obstacles, and glare.

In order to obtain maximum effect, the luminosity of the road surface must be produced by the particles protruding up from the surface, i.e. the coarsest portion of the aggregates.

There is no even nationwide distribution of usable light-colored aggregates. The usefulness is determined by the durability, the resistance to weathering, and the degree of luminosity. Most good deposits are located in western coastal districts. Later, the search was intensified inland as well. The main deposits have consisted of anorthosites and quartzites. Of these, the quartzites have the best wear properties, while the anorthosites are lighter in color. Luminosity class 1 contains both types; some light-colored gravel deposits are to be found in class 2.

The field tests of the Road Laboratory have confirmed the positive effect of a light-colored road surface or a light-colored shoulder on the recognition of obstacles on the road. The field tests have also shown satisfactory wear characteristics of those light-colored aggregates that had been selected on the basis of laboratory testing.

With the current geographical distribution of the deposits, the additional costs for using light-colored aggregates in road surfacing have been calculated at approximately 10%. Used in conjunction with fixed road illumination, however, the light-colored road surfaces may bring significant savings (10-130%) in installations necessary to fulfill the requirements of the Road Norms. Furthermore, one can expect relatively great gains in respect to increased traffic safety.

The guidelines of the Public Roads Administration have the following formulation in respect to the use of light-colored road surfaces: "Considering traffic safety, the main roads should successively be covered with continuous light-colored surfaces, even though the cost for such surfaces be somewhat higher than for standard road surface. In the first stage, priority should be given to roads with mixed traffic in densely populated areas. Light-colored road surfaces should also be used in tunnels."

In this context, light-colored surface means an addition of no less than 20% light aggregate, calculated from the total material mix but added to the coarse fraction.

The search to date indicates possibilities of finding more useful "light" deposits with a geographically more advantageous location than the currently known deposits. This will facilitate the fulfillment of the intentions expressed in the abovementioned guidelines within the economical framework of any given time.

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